Increasing the STEM Pipeline through Problem-Based Learning

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Abstract: Problem-based learning (PBL) is an instructional approach whereby students learn content by actively and collaboratively solving authentic, real-world problems. Used extensively in medical education since the 1970's, PBL has emerged as an exciting and effective alternative to traditional lecture-based instruction in science, technology, engineering and math (STEM) education. Research shows that PBL improves student learning and retention, critical thinking and problem-solving skills, teamwork, and the ability to apply knowledge in new situations – skills deemed critical for success in the 21st century workplace.

In "*Problem Based Learning for Sustainable Technologies: Increasing the STEM Pipeline*" (STEM PBL), the principles of PBL are being used to develop innovative, standards-based curricula with the aim of increasing students' interest and preparedness in pursuing STEM-related careers. STEM PBL is a project of the New England Board of Higher Education and is funded by the National Science Foundation. Currently, the project PIs are working with industry collaborators breaking new ground in "green" technologies to create a comprehensive series of online multimedia PBL resources focused on sustainability. Referred to as "STEM PBL Challenges," these instructional materials are designed to engage secondary and post-secondary students in real-world problem-solving.

The project teams STEM teachers from high schools with faculty from two- and four-year institutions of higher education from New England and across the country. In addition to providing professional development in both on-site and online formats to in-service teachers, the STEM PBL project will also create a model course in PBL methodology for pre-service middle and secondary school teachers. As a capstone project, these pre-service teachers will develop an original multimedia PBL Challenge on a STEM topic of their choosing. As a result, a collection of STEM-related PBL learning tools will evolve and be disseminated along with the details of the project and the results of research on its outcomes.

Introduction

Need for STEM Talent in the U.S. and National Statistics

Long-term growth in the number of positions in science and engineering has far exceeded that of the general workforce, with more than four times the annual growth rate of all

occupations since 1980 [1]. The most recent occupational projections from the Bureau of Labor Statistics [2] forecast that total employment in fields that the National Science Foundation classifies as science and engineering will increase at nearly double the overall growth rate for all occupations by 2014, growing by 26% from 2004 to 2014, while employment in all occupations is projected to grow 13% over the same period [3].
In spite of such promising job prospects, recruitment for science and engineering programs is a real challenge for most universities nationwide. Unfortunately, math and science are not the subjects of first choice for the majority of American high school students. According to the recent report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* in South Korea, 38% of all undergraduates receive their degrees in natural science or engineering. In France, the figure is 47%, in China, 50%, and in Singapore, 67%. In the United States, the corresponding figure is only 15% [4].

If the U.S. is to maintain its competitive edge in the global economy, the pipeline of interested and qualified students prepared to enter STEM careers must be increased. Yet recent results from a survey by the American Society for Quality (ASQ) revealed that more than 85% of students today are not considering careers in engineering and that more parents encourage their daughters to become actresses than engineers. Forty-four percent of survey respondents cited a lack of knowledge around engineering as the top reason they would not pursue such jobs. Another 30% listed the "geek" perception as their top reason, indicating that "engineering would be a boring career," according to the ASQ [5]. This is one of the most serious issues our nation will face over the next decade, as the current science and technology workforce retires without a pipeline of workers to replace them.

Equally alarming, international comparisons of student mathematics and science performance indicate that U.S. students scored below average among industrialized countries [3]. U.S. 15-year-olds ranked 27th out of the 39 countries participating in the 2003 Program for International Student Assessment (PISA) examination, designed to assess students' abilities to apply scientific and mathematical concepts to real-world problems [6]. Furthermore, the retention rate for engineering students is one of the lowest among all majors; one-third of all U.S. students intending to pursue engineering change majors before graduating [4].

Thus, improving the preparation of STEM teachers in the United States and the number of effective teaching tools available to them is critical if American students are going to keep pace with their counterparts internationally. Furthermore, the characteristics of instruction that best serve diverse student populations is a research area of particular need [7].

Problem-Based Learning

Overwhelming evidence exists that students from all backgrounds have the capacity to become proficient in math and science, and that children of all ages can and do engage in complex reasoning about the world [8, 9]. The National Academies reported in its recent publication, *Taking Science to School: Learning and Teaching Science in Grades K-8*, that "Comparisons of science standards and curricula in the U.S. with that of countries that perform well on international science tests reveal overly broad and superficial coverage of science topics in U.S. classrooms … an overemphasis on recipes for data collection

procedures—whether experimental, observational, or archival—may strengthen the misconceptions that some students hold about the so-called scientific method—the image that scientific discoveries emerge unproblematically if one just faithfully follows the steps outlined in the science text [8]."

One of the reasons for declining enrollment in many STEM programs is that students are often turned off by the way these subjects are typically taught, with traditional classroom lectures followed by "cook-book" type laboratory experiences that provide little opportunity to actively engage in creative, real-world problem solving. In 2008, the National Academy of Engineering identified "Advance personalized learning" as one of the "Grand Challenges for Engineering in the 21st Century," pointing out that "Throughout the educational system, teaching has traditionally followed a one-size-fits-all approach to learning, with a single set of instructions provided identically to everybody in a given class, regardless of differences in aptitude or interest. … In recent years, a growing appreciation of individual preferences and aptitudes has led toward more 'personalized learning,' in which instruction is tailored to a student's individual needs [10]."

Engineers and scientists are problem solvers— individuals who skillfully apply their knowledge to tackle real-world problems by designing experiments, building and troubleshooting prototypes, analyzing and interpreting data, and presenting experimental results to peers, supervisors and customers. It follows that to attract more students into STEM careers, students must be provided with more meaningful learning experiences in order to motivate and excite them—learning-experiences that relate directly to the world in which they live. They want and need active hands-on learning experiences that challenge them to explore new and emerging technologies that provide opportunities to "think outside the box" and apply their knowledge, skills and creativity in solving authentic real-world problems [11-14]. Problem-Based Learning (PBL) is capable of providing this type of learning experience.

PBL is an instructional method that challenges students to "learn how to learn" by collaboratively solving ill-defined, real-world problems. It is based on the constructivist model of learning and consists of four key components: 1) ill-structured problems that are likely to generate multiple hypotheses about their cause and multiple approaches to their solution, 2) student-centered learning, where students determine what it is they need to learn and find appropriate resources for information, 3) teachers acting as facilitators or tutors, and 4) authentic, real-world problems [15].

In PBL, students actively participate in their own learning by solving real-world problems in which the parameters are ill-defined and ambiguous. Unlike traditional instruction in which students attend lectures and solve well-defined end-of-chapter homework problems, PBL is open-ended and contextualized, and student learning is driven by the problem itself. With PBL, students learn the process of learning in addition to course content by engaging in a systematic and iterative process that begins with problem analysis, carefully and methodically dissecting a problem by reflecting on prior knowledge to identify knowledge gaps, situational constraints, and other pertinent problem features required to formulate a solution. Once the problem has been properly framed, students engage in self-directed learning to acquire the knowledge and skills needed to solve the problem. This is followed by

brainstorming possible solutions with peers, and finally solution testing, where students develop viable strategies to test and validate their solutions.

PBL has been used extensively in medical education since the early 1970's and research has shown that PBL improves student understanding and retention of ideas, critical thinking and problem-solving skills, motivation and learning engagement, and the ability to adapt their learning to new situations [16-19]. While PBL has been adopted in other fields of higher education including business and law, it is only beginning to emerge as an alternative to more traditional approaches in K-12 STEM education. Though not abundant, results from studies of PBL in K-12 STEM education are also promising. In a recent review article published in the *Journal of Engineering Education*, Litzinger et al. state "it is clear that [engineering] students would benefit from a greater number of opportunities to address authentic problems" and recommend PBL as an instructional approach that can be used to achieve this goal [20].

Some research even suggests an increased likelihood that at-risk students will succeed academically when provided with alternative learning environments such as PBL. A study of girls at risk of failing middle school math or science showed that all study participants had positive reactions to PBL, as evidenced by improvements in students' learning processes and self-efficacy [21]. A separate study compared the effectiveness of PBL and traditional instructional approaches in developing high school students' macroeconomics knowledge and found PBL to be more effective overall [22]. Interestingly, the results from this study also showed that PBL was particularly effective with students of average verbal ability and below, students who were more interested in learning economics and students who were most and least confident in their ability to solve problems.

While there is substantial evidence to suggest that PBL can be a valuable supplement to traditional, lecture-based instruction, its effectiveness depends on a variety of factors including variations in the implementation of PBL methodology and assessment of learning outcomes, as well as teachers' knowledge skills and attitudes towards PBL [23, 24]. A recent case study described the outcomes of one high school science teacher's exploration of PBL methods in her classroom [25].

> *For many teachers who have not experienced new methodologies as teachers or as learners, trying a new approach can be intimidating. If PBL is to become more prevalent in K-12 contexts, assuming this is a desirable goal, then teachers will need support and encouragement to try it. Deidre, who should be praised for her willingness to try something new in support of her students' learning, was uncomfortable with letting go of the control offered by her usual methods of instruction. She overcame this barrier, but completed the project still questioning the efficacy of PBL. Many teachers are driven to cover the curriculum, and adopting this more time-consuming approach is not consistent with coverage.*

Additional research into the factors affecting teachers' adoption of PBL may prove valuable in promoting more widespread use of this promising pedagogical approach.

Previous Work

To improve the readiness of teachers, including in-service and pre-service K-12 STEM educators, to incorporate PBL into their instructional methodologies, the STEM PBL project will build upon the successes of PHOTON PBL, a project of the New England Board of Higher Education (NEBHE) that was launched in 2006. Funded by the National Science Foundation (NSF), the PHOTON PBL project led to the development of eight multimedia PBL "Challenges" which were created in partnership with photonics industry and university partners and field-tested by more than 50 STEM educators from secondary and post secondary institutions across the U.S.. The PHOTON PBL Challenges are self-contained multimedia instructional modules designed to develop students' problem solving ability and understanding of photonics concepts and applications. The eight PHOTON PBL Challenges are listed below and are currently available at NEBHE's PBL web site (http://pblprojects.org), along with an Implementation Guide for Teachers and several related conference publications and resources which provide a complete description of this prior work.

The PHOTON PBL Challenges:

- *Stripping with light, fantastic!* – PhotoMachining Inc. in Pelham, NH needs to develop a laser-based process for stripping the coating from 50 micron wire.
- *DNA Microarray Fabrication* - Boston University graduate students need to determine the best starting exposure time for a DNA microarray fabricator.
- *High Power Laser Burn-In Test* – IPG Photonics in Oxford, MA needs a way to run 100-hour unattended burn-in tests on a 2-kilowatt laser.
- *Shining Light on Infant Jaundice* – Partners Photodigm, Drexel and SMU ask, "Can technology provide a safe and effective portable home treatment for newborn jaundice?"
- *Watt's my light?* – The package on an energy-saving light bulb says the 26 watt fluorescent has the same light output as a 100 watt incandescent. Can Cal Poly Pomona students verify this statement?
- *Of mice and Penn* – UPenn McKay Orthopaedic Research Lab graduate students study the healing of tendon injuries using mouse tendons. Can optics provide a non-contact method for measuring mouse tendon properties?
- *Hiking 911* – Two boys are lost in deep woods in rough terrain. Penn State Electro Optics Center (EOC) needs to recommend the best technology to locate them.
- *Blinded by the Light* – A man is arrested for blinding a pilot with a laser pointer. Is he innocent or guilty? Make your case.

Results of pilot tests revealed that with increased experience with the PBL Challenges, students' conceptual knowledge and problem-solving ability improved markedly. While pre-post measures of student content knowledge were not available for the study, instructor observations and comparisons of student performance in aggregate using traditional measures (homework, quizzes, and exams) for PBL students with performance of non-PBL students in the past showed that PBL students performed at least as well as non-PBL students. Results also revealed statistically significant increases in intrinsic motivation, self-efficacy, and metacognitive self-regulation. Finally, results showed a statistically significant increase in

metacognitive self-regulation—a key factor linked to students' ability to transfer knowledge and skills to new situations [26].

The STEM PBL Project

Building on the success of PHOTON PBL, the STEM PBL project will develop six additional PBL Challenges focusing on sustainable technologies to bring real-world problem solving experiences into an even broader range of STEM classrooms in an effort to develop students' critical thinking and problem solving skills and to expose them to the exciting career possibilities in sustainable technologies. Professional development opportunities for in-service and pre-service STEM educators will develop teachers' capacity for incorporating PBL instructional methods in their classrooms.

The STEM PBL project has four primary goals:

1. Develop six multimedia STEM PBL "Challenges" focused on sustainable technologies in collaboration with industry and university partners designed to appeal to secondary and post-secondary STEM students.
2. Create and implement a web-based professional development course for in-service STEM educators in PBL methodology and the implementation of the PBL Challenges in the classroom.
3. Develop a model one-semester classroom course in PBL instructional methods using the STEM PBL Challenges for use in pre-service technology and engineering teacher education programs.
4. Conduct research to inform future development of PBL instructional materials and courses.

Four of the six STEM PBL Challenges have been completed and are listed below. The remaining two are still in development.

<u>Completed STEM PBL Challenges</u>:

- *FloDesign* – Students need to design a new way to extract electrical energy from a wind turbine
- *RSL Fiber Systems* is designing an ergonomic and energy efficient lighting system for submarines
- *Cape Cod Cranberry Growers Association* – Can technology be used to make a cranberry bog more energy efficient?
- *TTF Watershed Partnership* – Can the problem of urban stormwater be addressed by local communities without investing in huge infrastructure projects?

The Anatomy of a PBL Challenge

Each PBL Challenge contains five main sections (Figure 1): (1) Introduction - An overview of the particular topic to be explored; (2) Company/University Overview - An overview of the organization that solved the problem to set the context of the problem; (3) Problem Statement - A reenactment of an authentic real-world photonics problem as originally

presented to the organization's technical team; (4) Problem-Discussion - A reenactment of the brainstorming session engaged in by the organization's technical team; and (5) Problem

Figure 1. Multimedia PBL Challenge interface.

Solution - A detailed description of the organization's solution to the problem. The Problem Discussion and Problem Solution sections are password-protected allowing instructors to control the flow of information and pace of instruction. Each of the five main sections contains additional information and resources (i.e., scripts, websites, spec sheets, etc.) intended to guide the student through the problem-solving process. Designed to be implemented using three levels of structure ranging from Structured (instructor led), to Guided (instructor guided), to Open-ended (instructor as consultant), the PBL Challenges provide the necessary scaffolding to assist students in the development of their problem-solving skills through a developmental continuum. By allowing students to gradually progress through the PBL Challenges along a developmental continuum, students can develop the knowledge, skills, and confidence to take responsibility for their own learning. Likewise, providing instructors with control over the learning process and user-friendly technical and pedagogical resources make it easy to implement PBL in their classrooms.

Another unique feature of the PBL Challenges is the "Problem-Solvers Toolbox." The Problem Solvers Toolbox is a resource designed to help students develop a systematic approach to problem solving through a four-stage recursive process as illustrated in Figure 2.

- *Problem Analysis* – Identifying what is known, what is unknown and needs to be learned, and identifying any problem constraints to properly frame the problem.
- *Independent Research* – Setting specific learning goals, identifying necessary resources, and developing a timeline and strategy for achieving those goals.
- *Brainstorming* – Productively engaging in collaboratively learning to identify the best course of action for solving the task at hand.
- *Solution Testing* – Developing a viable test plan to validate your potential solution based on specific performance criteria.

For each of the four processes, students click on an icon that reveals a "Whiteboard" graphic designed to emulate an actual classroom whiteboard. The Whiteboards, shown in Figure 3, provide a systematic method for students to capture their thoughts, ideas, and learning strategies during each stage of the problem solving process. Students may cycle through the whiteboards several times for a given problem, revising their problem solution each time

Figure 2. Problem Solving Toolbox with icons representing Problem Analysis, Independent Research, Brainstorming and Solution Testing.

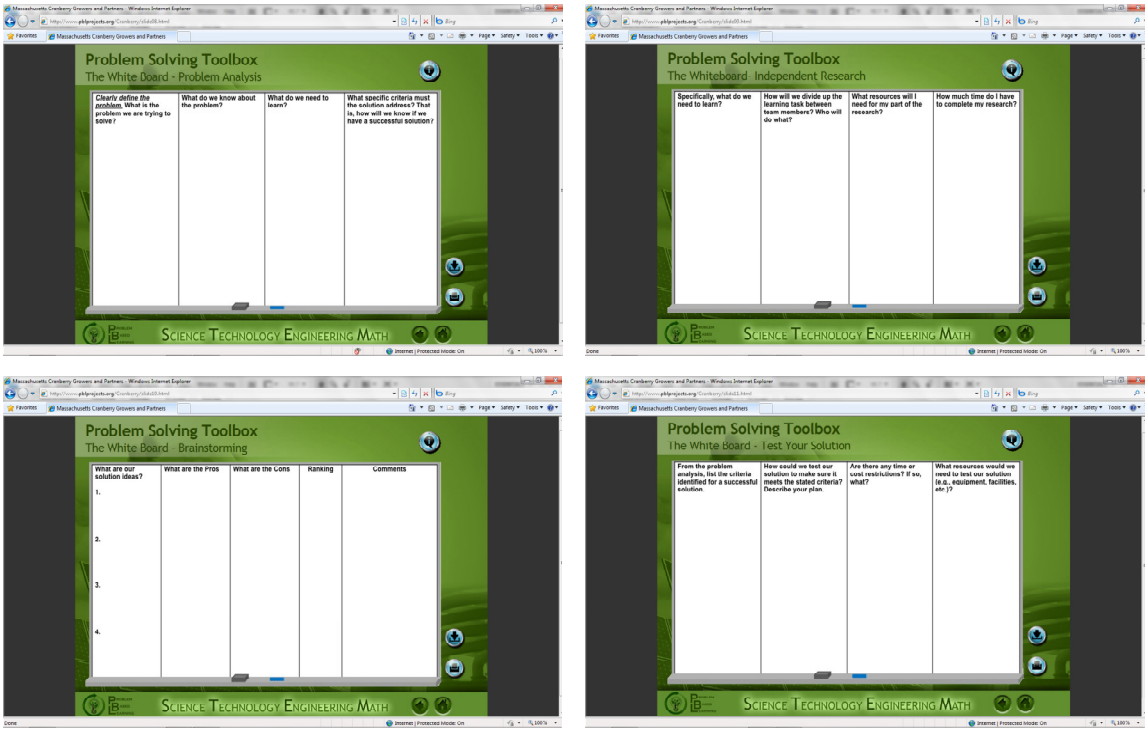

Figure 3. The STEM PBL Whiteboards for (clockwise from upper left) Problem Analysis, Independent Research, Brainstorming and Solution Testing.

Figure 4. Students using the Problem Analysis Whiteboard.

until they converge on an optimal solution. For instructional purposes, the Whiteboards can either be printed or projected/copied onto an actual classroom whiteboard. (see Figure 4).

For instructors, a comprehensive "Teacher Resource" section is included (see Figure 5) that provides technical background on the main concepts introduced, assessment strategies, implementation stories detailing how other instructors at different educational levels have

Figure 5. Teacher Resources.

implemented the PBL Challenge, a guide for standards alignment and a "PBL How-To Video" illustrating the use of the PBL Challenges in the classroom.

Assessing student learning in PBL often presents a unique challenge for educators accustomed to traditional assessment methods used in lecture-based instruction. The method used to assess student learning in the PBL Challenges is based on a three-pronged "adaptive

expertise" model adapted from the Vanderbilt-Northwestern-Texas-Harvard-MIT (VaNTH) Research Center for Bioengineering Educational Technologies [27] which involves three measures: content knowledge, conceptual knowledge, and problem-solving ability (see

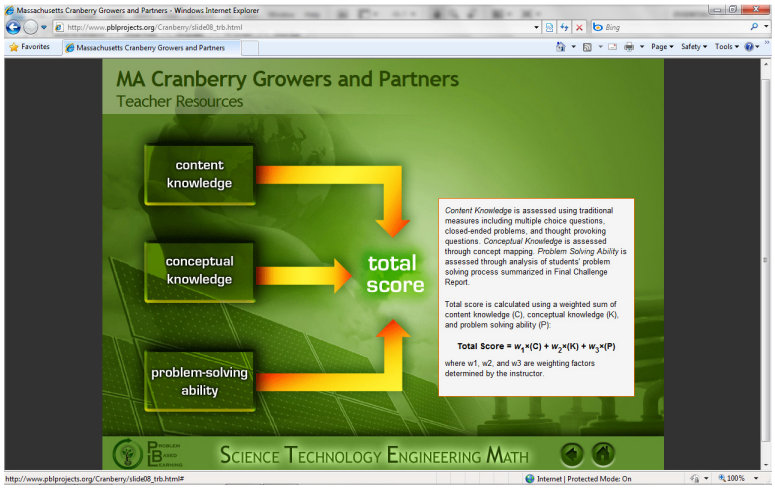

Figure 6. Student assessment strategies.

Figure 6). A weighted average calculated for the three measures results in a final composite score. Specific weights may be assigned by the instructor depending on the specific course format.

To assess content knowledge, the PBL Challenges include a test bank consisting of multiple-choice questions, closed-ended problems, and higher-level thought provoking questions centered on specific technical content associated with the particular problem. Conceptual knowledge refers to a student's understanding of and relationship between key concepts underlying a particular domain of knowledge. To assess conceptual knowledge, the PBL Challenges include a list of main concepts related to the topic being explored, a reference or "expert" concept map for instructors, detailed instructions for students on how to construct a concept map, and a concept map scoring rubric. Assessing problem solving ability involves both formative and summative assessments. Formative or in-process assessment is accomplished via the Whiteboards. As students collaboratively engage a problem by completing the four Whiteboards, they reflect upon and elucidate their current state of understanding, their thought processes, and problem solving strategies. Research shows that verbalizing the thought process while engaging in problem solving improves metacognition, which is essential for effective problem solving [28]. Summative or post-process assessment is accomplished through a Final Challenge Report. The Final Challenge Report is a reflective journal that requires students to provide a detailed summary and critical analysis of the problem-solving process employed in solving the PBL Challenge. Researchers maintain that this final reflective exercise is essential in the development of effective problem-solving skills [29]. A scoring rubric is provided to grade the Final Challenge Report.

Web-Based Professional Development for In-Service Educators

Over the 2009-2010 academic year, thirty secondary, community college, and four-year college and university in-service STEM educators were recruited nationwide to take part in a 15-week online course. The online course is being conducted in three 5-week sessions in fall

2010, winter 2011 and spring 2011, for a total of 90 hours of coursework, with a break of 6-8 weeks between sessions. Experience gleaned from prior online course delivery [30] revealed that participants perform better in short-term sessions with time in between to reflect on the experience and begin to plan implementation of the course material in their own classrooms.

Experienced PBL instructors from the PHOTON PBL project have also enrolled in the course as mentors who monitor discussions and provide guidance to new faculty. Course participants work in small teams of 3-4 teachers to model the dynamics of how the PBL Challenges will be used in their classrooms. Using Blackboard Vista® as a course delivery platform, participants work to solve three STEM PBL Challenges, beginning with a Structured format (Session I), then a Guided format (Session II), and finally an Open-ended format (Session III) through threaded discussions and online chats. From session to session, the participants are given greater autonomy as more responsibility is placed on them to self-direct their own learning. The course structure, from highly structured to open-ended will emulate the way instructors will use Challenges with their own students. Between online class sessions, participants will collaborate with each other, PHOTON PBL mentors and the STEM PBL project team to explore how best to incorporate the PBL Challenges into their own classroom and curriculum.

Prior to the online course, a two-day introductory workshop was held in early fall 2010 at a central location to acquaint participants with the online learning environment and the PBL Challenges, and to create a learning community to foster online collaboration. All participants were added to the PBL listserv; an email listserv managed by the New England Board of Higher Education (NEBHE) and composed of a nationwide network of PBL educators, educational researchers, and industry mentors. Employees of partner industries and research universities also participate in the listserv to provide ongoing technical support to educators.

A Model Classroom Course for Pre-Service Technology and Engineering Educators

In addition to providing professional development to in-service teachers, the STEM PBL project will also create a model course in PBL methodology using the STEM PBL Challenges for technology and engineering education (TEE) majors (pre-service middle and high-school teachers). To accomplish this goal, an existing required classroom course in instructional methods at Central Connecticut State University (CCSU) is being adapted to include PBL theory and applications. The course, TE 399, is currently offered once per year and the new PBL-based version will be delivered for the first time in spring 2011. TE 399 is required of all TEE undergraduates at CCSU and students must have taken at least one practicum course in the program and achieved junior status prior to enrolling. A course description follows:

> *<u>TE 399</u>: Development of knowledge and skills needed by an individual to function as a professional technology education teacher. Preparation, presentation and evaluation of student-developed lessons and methods of student assessment, unique to technology education laboratories, will be emphasized.*

Similar to the online course, students will work to solve three STEM PBL Challenges, first as a Structured problem, then as Guided and Open-ended. As a capstone project for the course, students will use the pedagogical strategies and technical skills they acquire throughout the semester to develop an original multimedia PBL Challenge on a STEM topic of their choosing. As a result, a collection of STEM-related PBL learning tools will evolve and will be disseminated through the NEBHE PBL web site.

Research Methods

As demonstrated by the literature cited previously, there is a great deal of evidence to suggest that there are multiple benefits to be realized by using PBL. The research also shows, however, that PBL requires time and effort in gaining acceptance and that more work is necessary to improve teachers' skills in facilitation and attitudes toward self-directed learning. To address this need, the STEM PBL project is currently conducting quantitative and qualitative research into teachers' knowledge, skills and attitudes concerning PBL and their self-efficacy with regard to its implementation. The project will also examine the extent to which specific online professional development activities contribute to changes in teaching practices (i.e., transfer of training) among participating in-service teachers and compare these results with the outcomes of the pre-service course.

To accomplish this, the Motivated Strategies for Learning Questionnaire (MSLQ) will be administered to the in- and pre-service teachers at the beginning and end of their respective courses. The MSLQ is an online survey consisting of 81 statements regarding motivation for learning and learning strategies to which students are asked to respond using a 7-point scale, from 1 ("Not true of me at alI") to 7 ("Very true of me") [31]. The questionnaire, which takes approximately 20 minutes to complete, will be customized in order to specifically assess teachers' perceptions of PBL. The results from the MSLQ surveys will be triangulated with data from pre- and post-tests on PBL content knowledge as well as samples of course work and comments from focus groups. Informed consent will be required of all participants.

Conclusion

In this paper, we presented the STEM PBL project, a three-year NSF-funded project aimed at increasing the STEM pipeline through PBL focused on sustainable technologies. We discussed how the STEM PBL project team, building on their prior work on the NSF-funded PHOTON PBL project, is now working with industry and research universities breaking new ground in sustainable and green technologies to create a comprehensive series of multimedia PBL Challenges designed to engage students in real-world problem solving. A detailed summary of the PBL Challenge model was presented as well as a description of the online professional development course currently being offered over the 2010-2011 academic year for in-service teachers in PBL instructional methods using the STEM PBL Challenges. We also described the development of new classroom course in PBL instructional methods for pre-service TEE teachers scheduled for implementation in spring 2011. Finally, we presented a discussion on the research activities scheduled to take place to evaluate the efficacy of the new multimedia STEM PBL Challenges with regard to the learning outcomes and transfer of training among participating faculty.

References

[1] *Report of the National Science Board Committee on Education and Human Resources Task Force on National Workforce Policies for Science and Engineering, NSB 03-69*. 2003. p. 61-61.

[2] Bureau of Labor Statistics, *National Industry-Occupation Employment Projections 2004-2014*. 2006, Department of Labor: Washington, DC.

[3] National Science Board, *Science and Engineering Indicators, 2008. Volume 1. NSB-08-01*. 2008, National Science Foundation: Arlington, VA.

[4] *Rising Above the Gathering Storm: Energizing and Employing America to a Brighter Economic Future*. 2005, National Academy of Sciences, National Academy of Engineering and Institute of Medicine of the National Academies: Washington, DC.

[5] (2009) *Mommas don't let their babies grow up to be engineers*. ITworld. Accessed February 13, 2009, http://www.itworld.com/career/62315/mommas-dont-let-their-babies-grow-be-engineers.

[6] National Center for Education Statistics, *International Outcomes of Learning in Mathematics Literacy and Problem Solving: PISA 2003 Results From the U.S. Perspective: Highlights. NCES 2005-003*. 2004, U.S. Department of Education: Washington, DC.

[7] Richard A. Duschl, Heidi A. Schweingruber, and Andrew W. Shouse, eds. *Taking Science to School:Learning and Teaching Science in Grades K-8*. ed. C.o.S. Learning. 2007, National Academies Press: Washington, DC.

[8] *Taking Science to School:Learning and Teaching Science in Grades K-8*, R.A. Duschl, H.A. Schweingruber, and A.W. Shouse, Editors. 2007, National Research Council: Washington, DC.

[9] *How People Learn: Brain, Mind, Experience, and School*, C.o.D.i.t.S.o. Learning, et al., Editors. 2000, National Research Council: Washington, DC.

[10] *National Academy of Engineering: Grand Challenges for Engineering*. Available from: http://www.engineeringchallenges.org/.

[11] *Strengthening the Science and Mathematics Pipeline for a Better America*, in *Policy Matters*. 2005.

[12] M.J. Johnson and S.D. Sheppard, *Students Entering and Exiting the Engineering Pipeline – Identifying Key Decision Points and Trends*, in *Frontiers In Education Conference*. 2002.

[13] H. Kimmel and R. Cano, *K-12 and Beyond: The Extended Engineering Pipeline* in *Frontiers in Education Conference*. 2001.

[14] T. Camp, *The Incredible Shrinking Pipeline.* Inroads: SIGCSE Bulletin, 2002. **34**(2): p. 129-134.

[15] Howard Barrows, *Is it Truly Possible to Have Such a Thing as dPBL?* Distance Education, 2002. **23**(1): p. 119-122.

[16] J.R. Savery and T.M. Duffey, *Problem-based learning: An instructional model and its constructivist framework*, in *Constructivist learning environments: Case studies in instructional design*, B.G. Wilson, Editor. 1996, Educational Technology Publications: Englewood Cliffs, NJ.

[17] H.S. Barrow, *A Taxonomy of Problem-based Learning Methods.* Medical Education, 1986. **20**: p. 481-486.

[18] N.M. Massa, et al., *Problem-Based Learning in Photonics Technology Education*, in *International Society for Optical Engineering (SPIE) Annual Conference*. 2008: San Diego, CA.
[19] C.E. Hmelo-Silver, *Problem-Based Learning: What and How Do Students Learn?* Educational Psychology Review, 2004. **16**(3).
[20] T.A. Litzinger, et al., *Engineering Education and the Development of Expertise.* Journal of Engineering Education, 2011. **100**(1): p. 123-50.
[21] N. Cerezo, *Problem-based learning in the middle school : A research case study of the perceptions of at-risk females.* Research in Middle Level Education Online, 2004. **27**(1).
[22] John R. Mergendoller, Nan L.Maxwell, and Yolanda Bellisimo, *The Effectiveness of Problem-based Instruction: A Comparative Study of Instructional Methods and Student Characteristics.* The Interdisciplinary Journal of Problem-based Learning, 2006. **1**(2): p. 49-69.
[23] David Gijbels, et al., *Effects of Problem-Based Learning: A Meta-Analysis from the Angle of Assessment.* Review of Educational Research, 2005. **75**(1): p. 27-61.
[24] Janet D. Ward and Cheryl L. Lee, *Teaching Strategies for FCS: Student Achievement in Problem-Based Learning Versus Lecture-Based Instruction.* Journal of Family and Consumer Sciences, 2004. **96**(1): p. 73-76.
[25] Karen Goodnough and Marie Cashion, *Exploring Problem-Based Learning in the Context of High School Science: Design and Implementation Issues.* School Science and Mathematics, 2006. **106**(7): p. 280.
[26] N.M. Massa, et al., *Problem-based learning in photonics technology education: Assessing student learning*, in *Education and Training in Optics and Photonics (ETOP) Conference*. 2009: Wales, United Kingdom.
[27] M.G. Pandy, et al., *Assessing Adaptive Expertise in Undergraduate Biomechanics.* Journal of Engineering Education, 2004. **93**(3): p. 1-12.
[28] R.L. Domoinowski, *Verbalization and Problem Solving*, in *Metacognition in Educational Theory and Practice*, D.J. Hacker, J. Dunlosky, and A.C. Graesser, Editors. 1998, Erlbaum: Mahwah, NJ.
[29] G. Polya, *How to Solve It: A New Aspect of Mathematical Method*. 2nd ed. 1957, Princeton, NJ: Princeton University Press.
[30] N. Massa, et al., *Learner Interaction and Self-Regulation in Web-Based Professional Development*, in *Annual Conference of the American Society for Engineering Education*. 2005: Portland, OR.
[31] Paul R. Pintrich and David A. F. Smith, *Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ).* Educational & Psychological Measurement, 1993. **53**(3): p. 801.

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